MetroLaser, Inc.

Fiber Optic Sensor for Industrial Process Measurement and Control (CPS# 1604)

Peter DeBarber and Tom Jenkins

Materials, Sensors & Automation, and Glass Project Review

June 21-24, 2004

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Fiber Optic Sensor for Industrial Process Measurement and Control (CPS# 1604)

Goals: Develop non-intrusive temperature and chemical sensor - maintaining high accuracy, large dynamic range, affordability, ruggedness, and high temporal resolution.

Challenge: Sensor based on near IR DFB lasers show promise but lack sensitivity for certain applications.

Benefits: DFB lasers operate at room temperature, fiber optic compatible, rapid measurement, minimal optical access required.

FY05 Activities: Develop robust calibration procedure, demonstration testing at industrial site/s, launch first generation commercial product.

Participants:

MetroLaser, Inc.
Bergmans Mechatronics LLC
GE EERC
UC Irvine

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Fiber Optic Sensor for Industrial Process Measurement and Control (CPS# 1604)

Barrier-Pathway Approach

Barriers

- Difficult to measure temperature and chemicals in high temperature combustion applications
- Lack of robust, affordable, rapid sensors for control and monitoring tasks

Pathways

- Development of non-intrusive fiber-coupled optical sensor
- Spectral modeling (H_2O) to find match with commercial DFB laser sources
- Laboratory testing to validate model
- Industrial site demonstration testing
- Commercialization

Critical Metrics

- Temperature Range: 900 – 2500K
- H_2O levels: 60 ppb/m
- Accuracy: +/- 50K
- Sample rate: 200 Hz
- Path length: 30 cm – 10 m

Potential Benefits

- Active combustor control
- Increase efficiency
- Minimize pollutants
- Process quality control

Motivating Example

Type K thermocouple failing near 2000K in methane/air flame

TC Shortcomings:

- Intrusive
- Fragile
- Time lag
- Radiation errors
- Conduction errors
- Frequent replacement
- …

Solution

Tunable diode laser absorption spectroscopy

Near IR DFB Laser:

- Non-intrusive
- COTS telecom technology (inexpensive, ~$100/laser AND available)
- Room temperature operation (no cryogenics required)
- Robust (fiber and free space compatible)
- High temporal resolution (~50 μs)
- High accuracy (~2.5%); high precision (~1.0%)
- Minimal optical access (line-of-sight)
- High spatial resolution (normal to beam)
- Large dynamic range (spanning combustion temperatures)
- Capability for higher pressures (< 20 atm)
- Self calibrating (spectral database)

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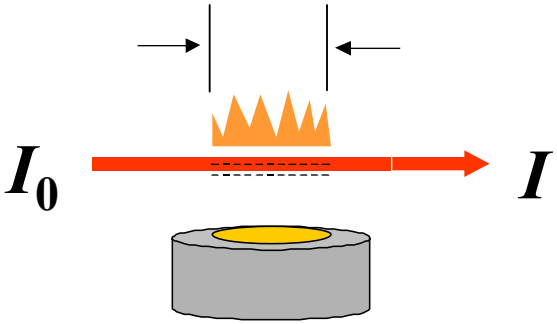
Background Theory

Tunable diode laser absorption spectroscopy

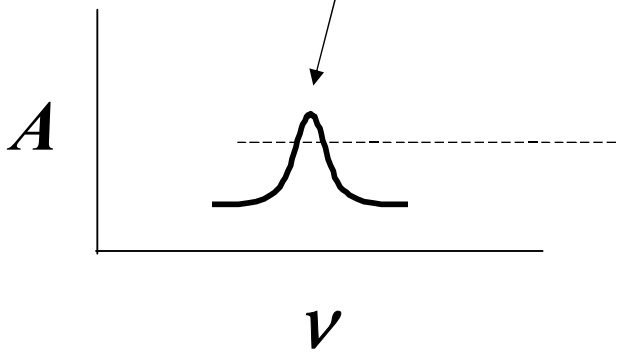
Scanned Wavelength Absorption Measurement:

- Direct absorbance or
- Wavelength modulation spectroscopy



$$\frac{I}{I_0} = \exp\left(-k_{v,i}L\right)$$

$$k_{\nu,i} = PXS_i(T)\phi_{\nu,i}$$



Temperature Extraction

- Absorbance at line center measured for two transitions
- Ratio is a function of only temperature

$$R = \frac{k_{\nu_0,1}}{k_{\nu_0,2}} = \frac{PXS_1(T)\phi_{\nu_0,1}}{PXS_2(T)\phi_{\nu_0,2}} = \frac{S_1(T)}{S_2(T)}$$

$$R = \frac{S_{0,1}}{S_{0,2}} \exp\left[-\frac{hc(E_1" - E_2")}{k}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

R&D Approach

Water vapor spectral line selection

- Line pair spacing
- Insensitivity to ambient absorption
- Wavelength availability
- Combustion temperature sensitivity

HITRAN spectral Simulation

- HiTEMP – your mileage may vary,…

Experimental Validation – static cells, flat flames,…

Prototypes – several versions

Demonstrations

1st Generation Product

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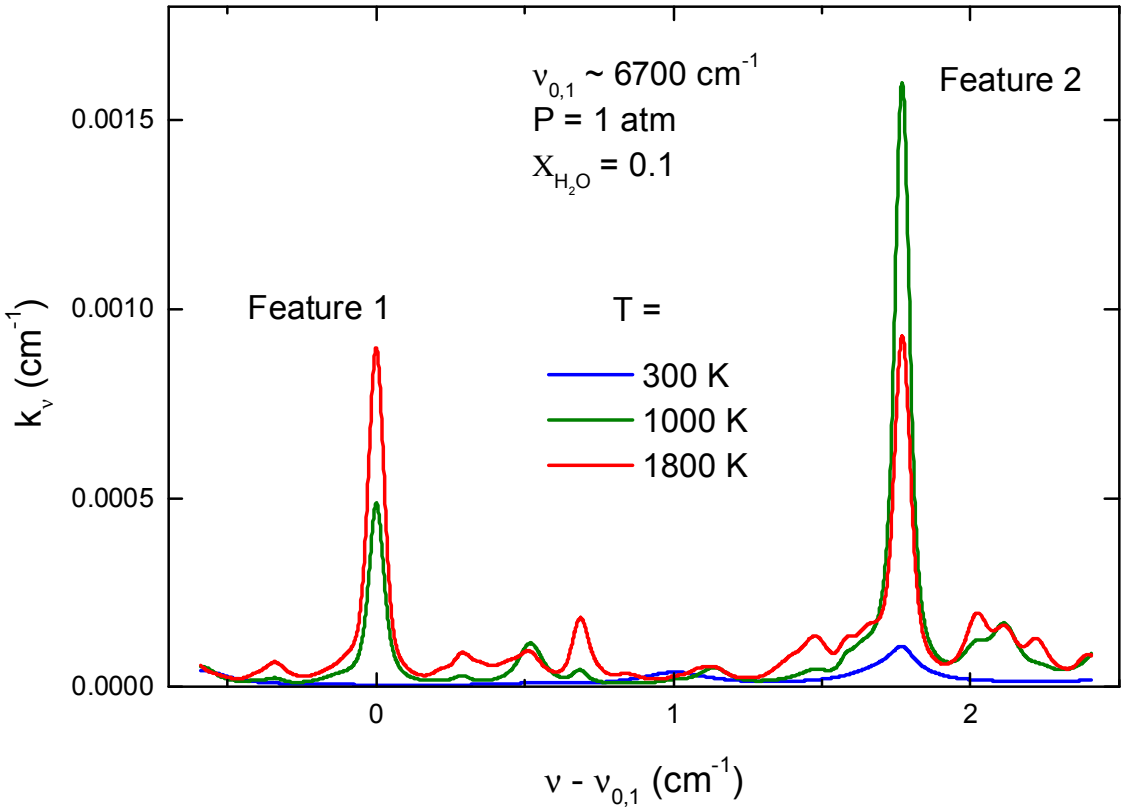
Spectral Simulation Example



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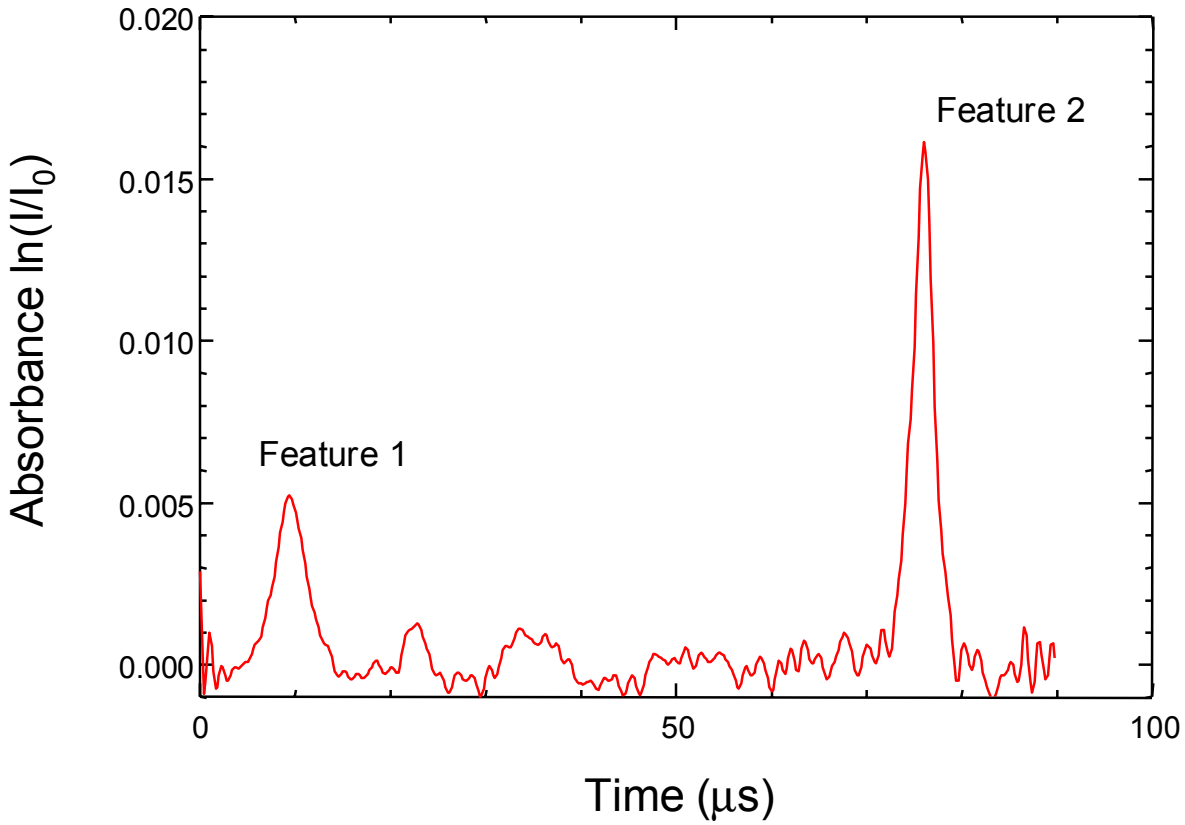
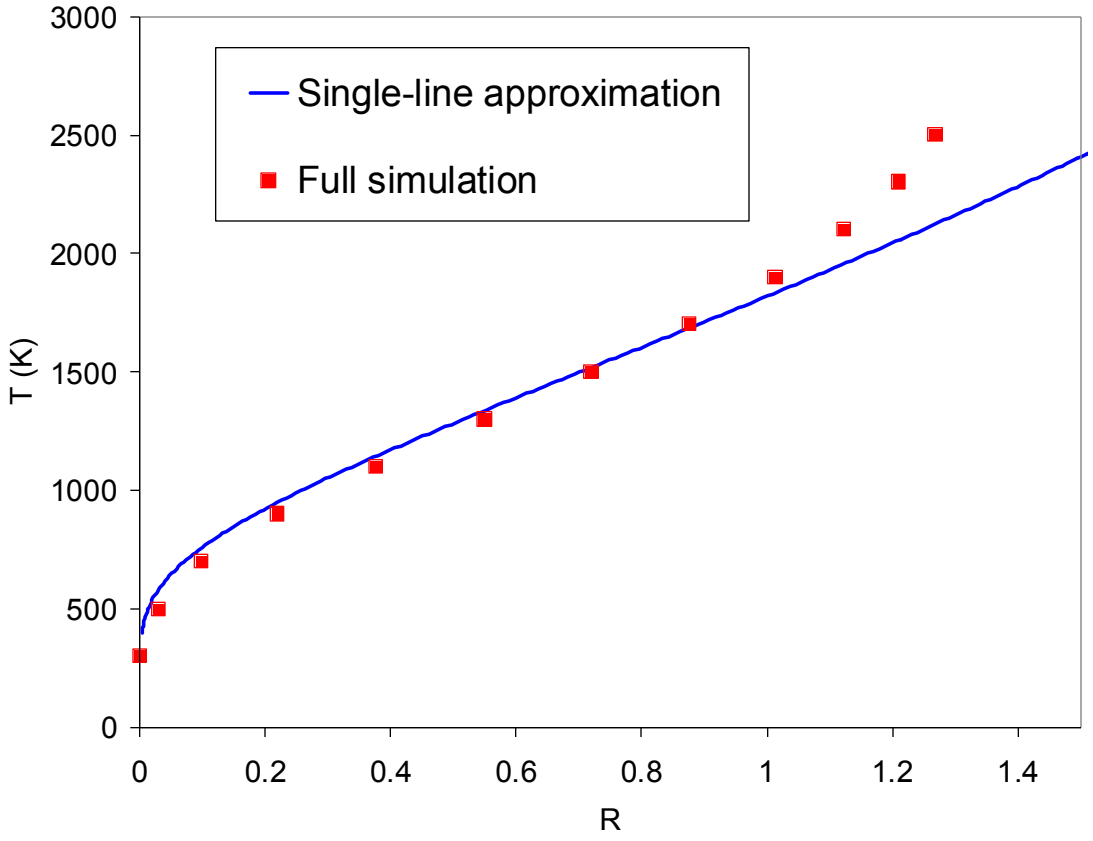
Observed Spectrum



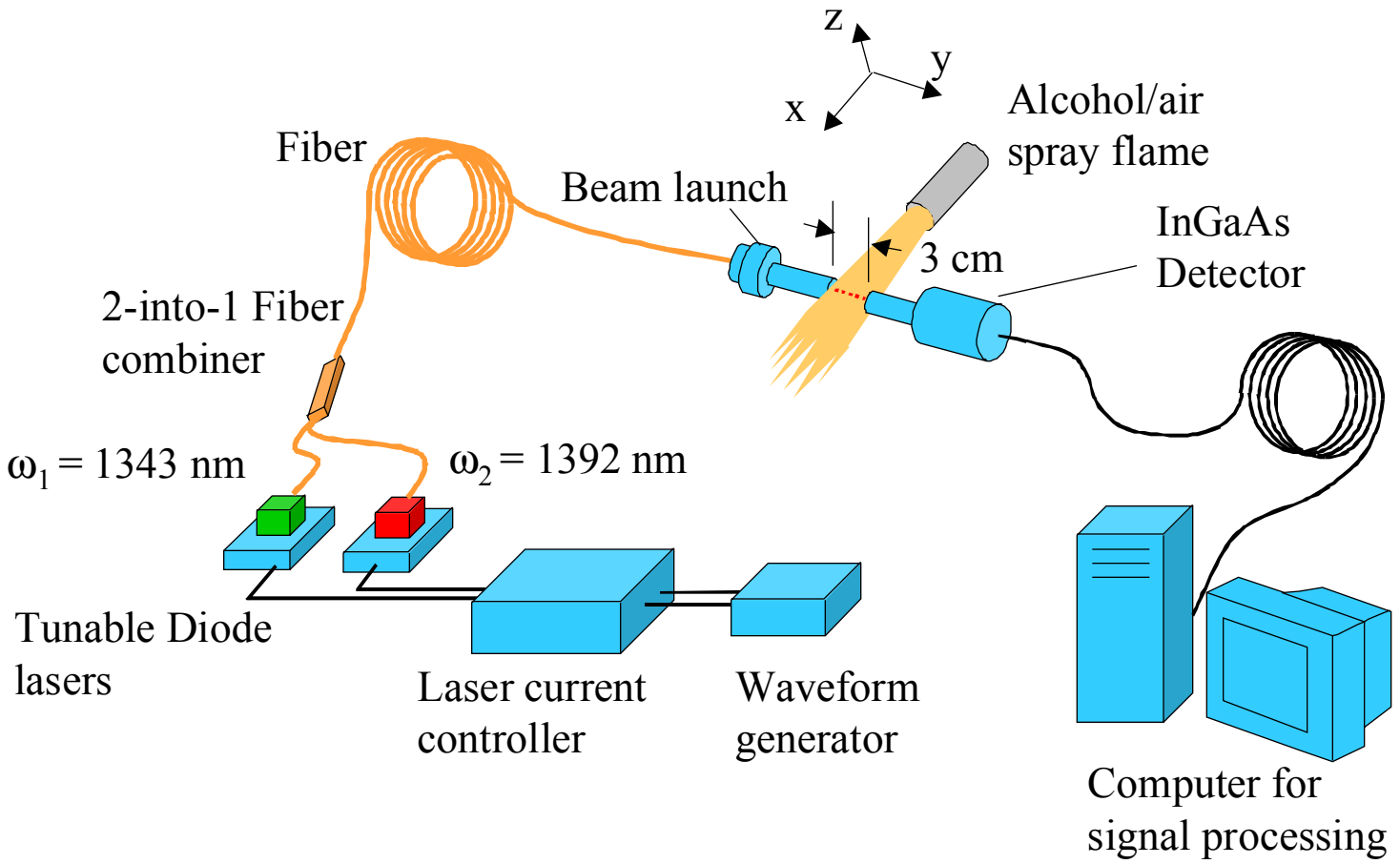
Temperature Calibration Curve



Progress to Date

- Identified relevant absorption features and simulated spectra
- Verified experimentally HITRAN database and simulated spectra
- Demonstrated a two-laser strategy on industrial chemical vapor deposition torch
- Demonstrated a single-laser strategy on industrial combustor
- Simultaneously accessed two spatial channels
- Demonstrated excellent correlation to chemiluminescence data
- Demonstrated high temporal and spatial resolutions
- Designed and built a demonstration system
- Entered into distributorship agreement

Combustion Chemical Vapor Deposition Application



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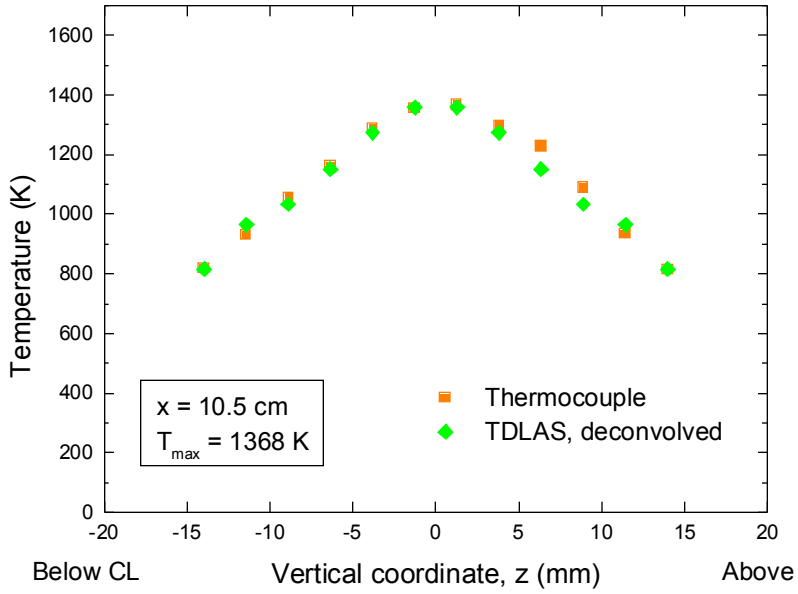
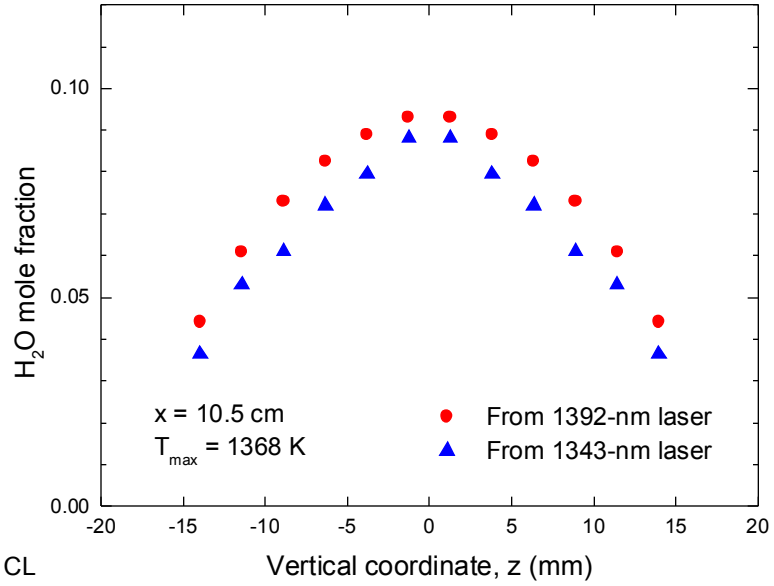
Combustion Chemical Vapor Deposition Application

Temperature



Mole Fraction



Excellent agreement up until TC failure

Agreement within 10%; discrepancy increases towards nozzle

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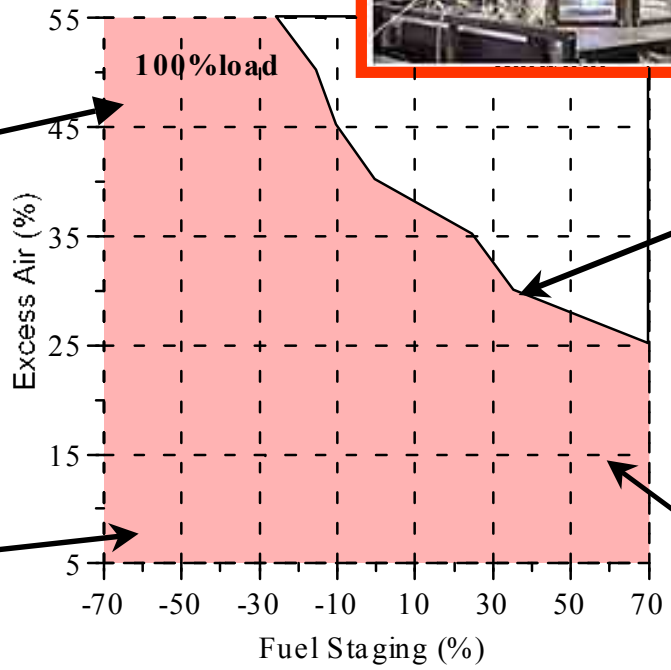
Low NOx Combustor Application



chemiluminescence

Diode laser positions

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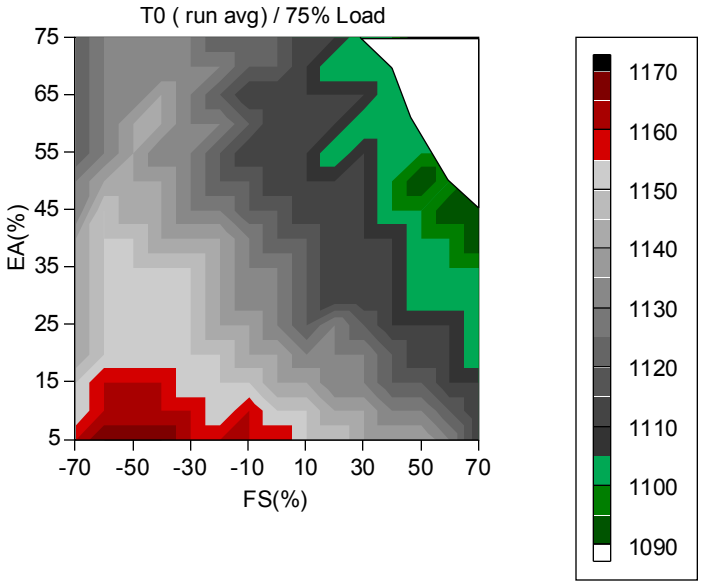
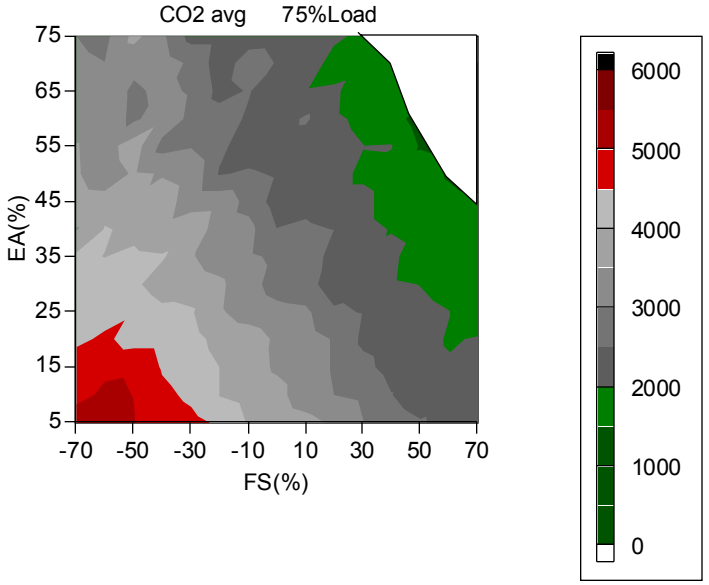
Low NOx Combustor Application

Diode Laser



Chemiluminescence



EA = excess air, above stoichiometric

FS = fuel split/staging, premix behavior < 0 < diffusion flame behavior

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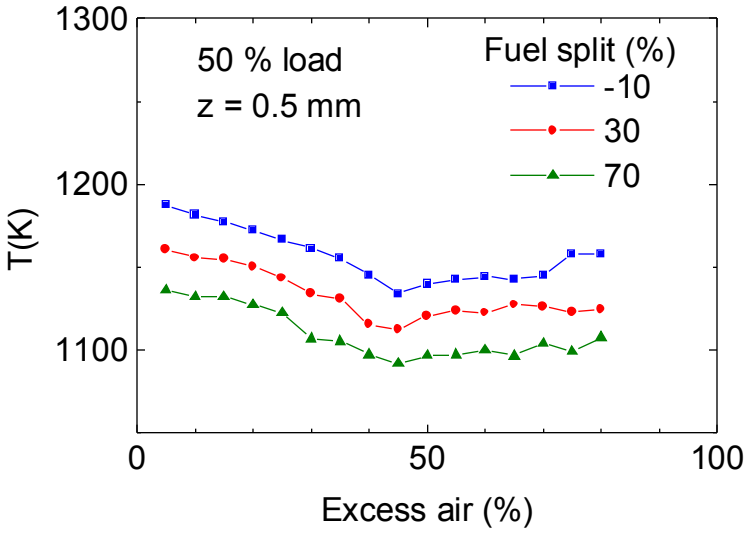
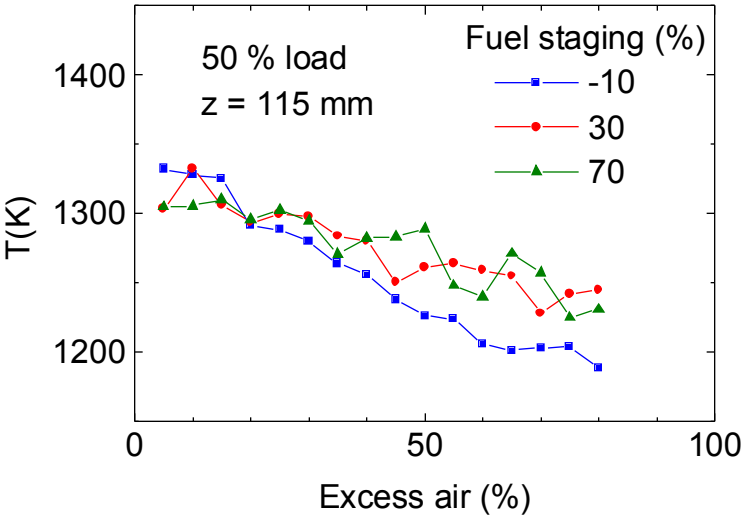
Low NOx Combustor Application

Next to nozzle



Downstream from nozzle



Clear differentiation between staging regimes close to nozzle; not resolvable with chemiluminescence

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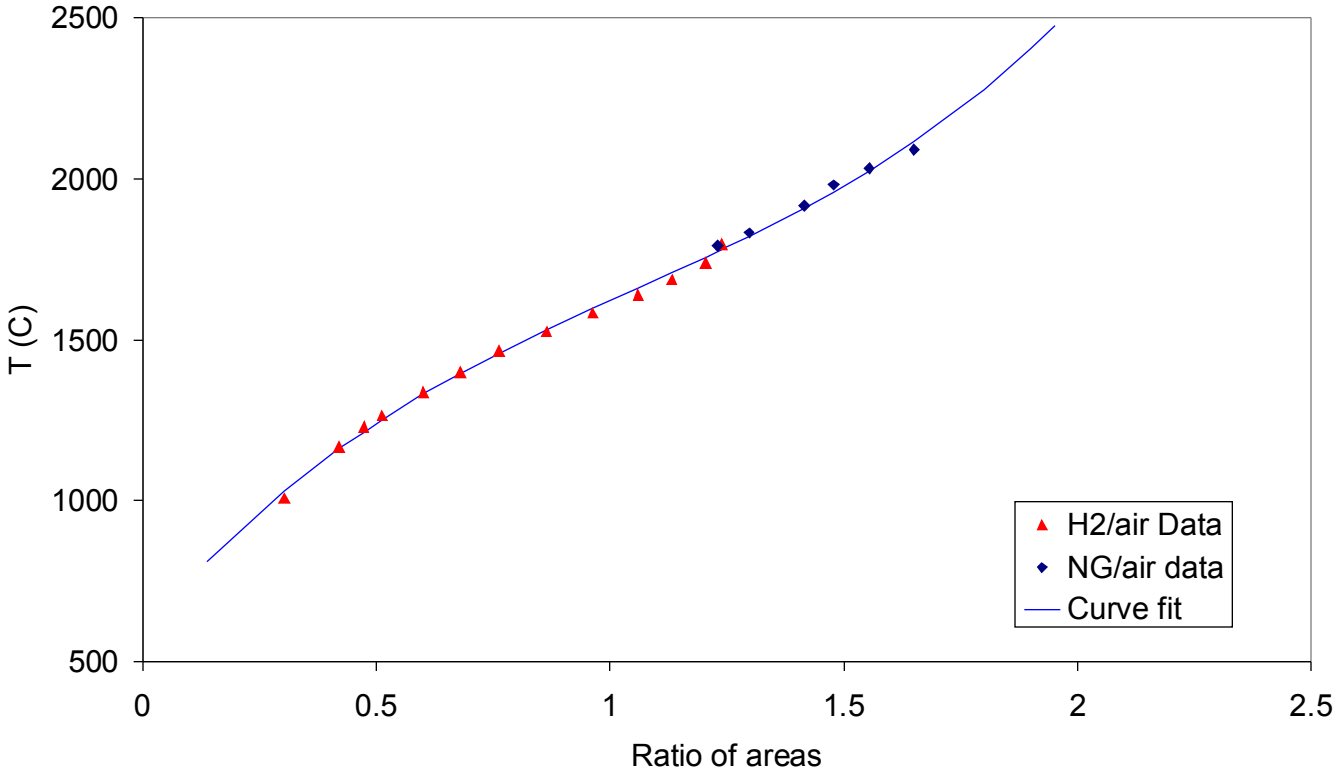
High Temperature Calibration



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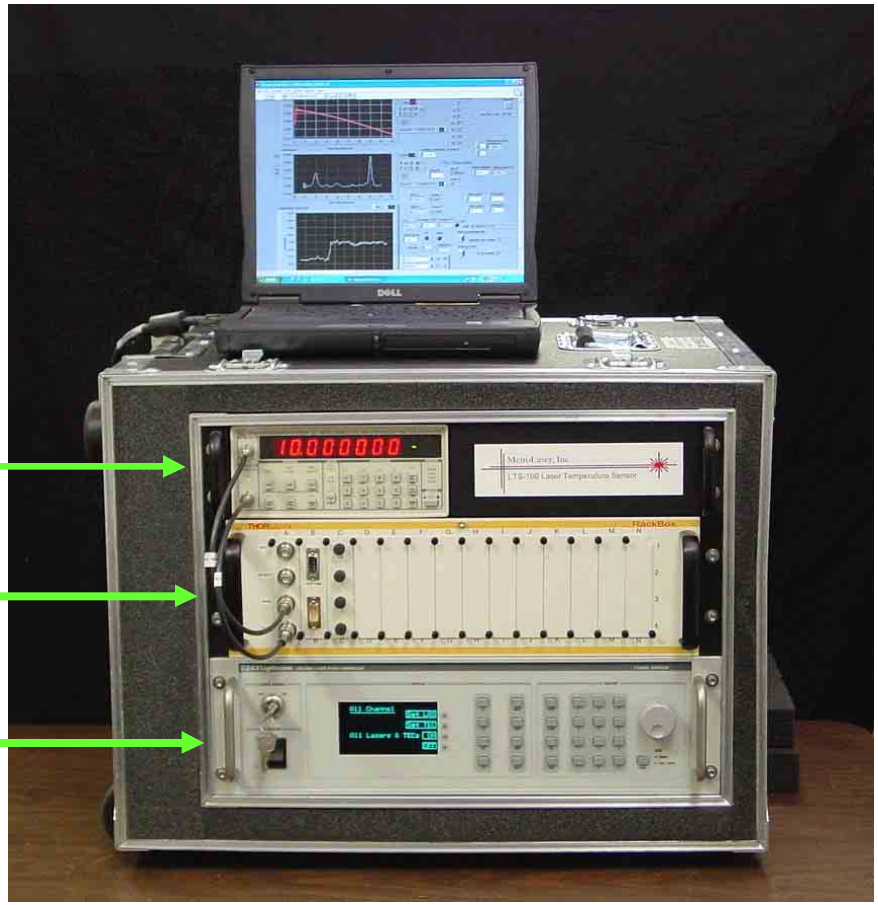
Demonstration System/1st Generation Product

Function generator

Laser and A/D board

Laser diode controller



Commercialization

Distributorship agreement:

Bergmans Mechatronics LLC

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Madison, AL 35758

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e-mail: jbergmans@bergmans.com
web: www.bergmans.com

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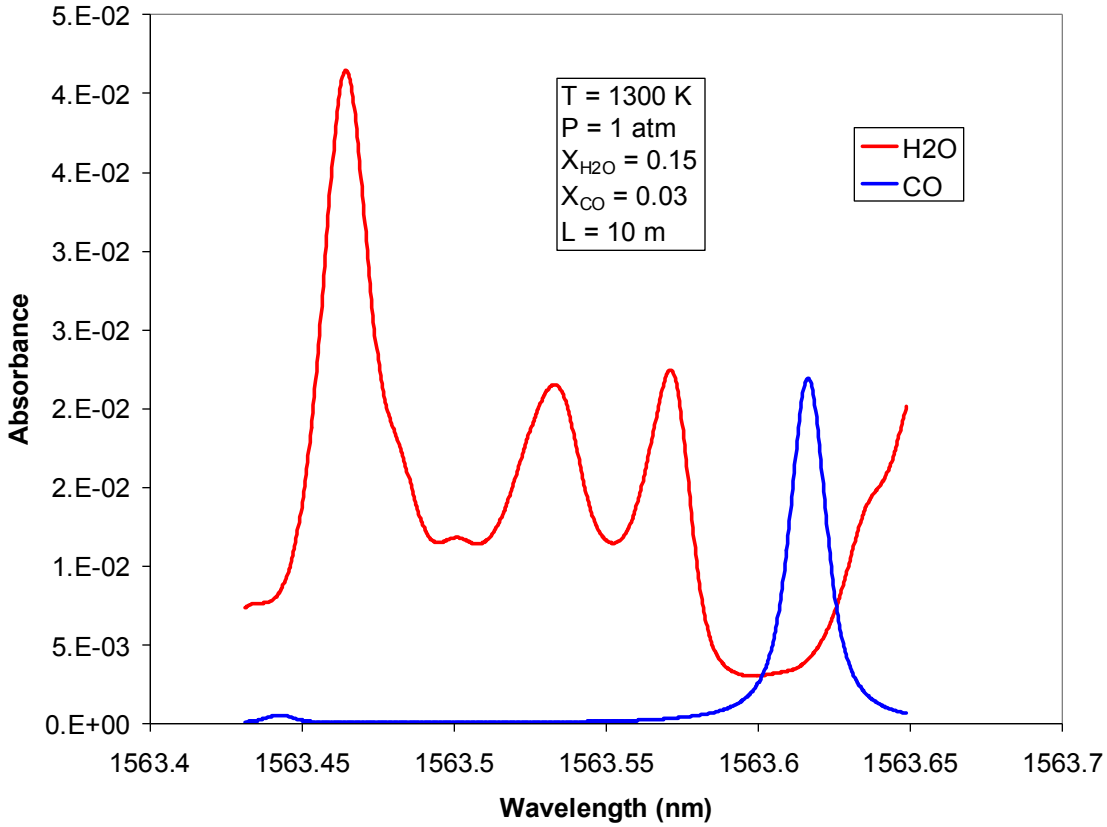
Future Refinements

- Simplify electronics package
- Add multipass cell (demonstration and calibration)
- Add channel for CO (see plot below)



Upcoming Demonstration Testing

- Steam methane reformer (fuel cell application)
  - GE EERC, Irvine, CA
  - Simultaneously measure H_2O and temperature at the inlet and outlet

- *Coal-fired power plant application*
  - *EPRI, TVA ,Kingston, TN*
  - *Temperature at one location*

- *Boiler simulator*
  - *GE EERC, Irvine, CA*
  - *Temperature at multiple locations*

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